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Executive Summary

Flood hazard and flood risk assessments are an integral part of the flood risk management cycle and are required by the EU Floods Directive for each Member State. However, the national design of the requirements varies considerably across the EU altogether and the Euregio Meuse Region in particular. On the basis of interviews with experts, the national administrative regulations and technical arrangements of flood risk assessment were compared for the Euregio Meuse regions in Germany, Belgium and the Netherlands.

In all three countries, flood risks are considered at regional level, which has the advantage that local expert knowledge can be included. However, in Germany and Belgium, monetary flood damages are not yet calculated to determine flood risk. Instead, various semi-quantitative approaches exist for estimating flood risk and prioritising flood protection measures. In the Netherlands, quantitative models for assessing monetary damages are used. Two main models emerge, one being used at the level of large flood events such as breaches, the other at the level of regional settings combined with low inundation flooding. Within the limits of their application of small to large floods, these models provide interesting quantitative results.

A further development of existing damage models could standardise the currently heterogeneous situation with regard to the calculation of monetary flood damage and flood risk. However, this requires comparable data on flood damages in the three countries.

Zusammenfassung

Hochwassergefahren- und Hochwasserrisikobetrachtungen sind ein integraler Bestandteil des Hochwasserrisikomanagementkreislaufs und werden von der EU Hochwasserrisikomanagement Richtlinie für jeden Mitgliedsstaat gefordert. Allerdings sind die nationalen Ausgestaltungen der Vorgaben EU-weit als auch in der Euregio Maas Region sehr unterschiedlich. Auf Grundlage von Experteninterviews wurden die nationalen administrativen Regelungen und fachlichen Ausgestaltungen der Hochwasserrisikobetrachtung für die Euregio Maas Regionen in Deutschland, Belgien und den Niederlanden herausgearbeitet.

In allen drei Ländern werden Hochwasserrisiken auf regionalen Skalen betrachtet, was den Vorteil bringt, dass lokales Expertenwissen miteinbezogen werden kann. Allerdings werden in Deutschland und Belgien noch keine monetären Hochwasserschäden berechnet, um das Hochwasserrisiko zu bestimmen. Vielmehr existieren unterschiedliche semi-quantitative Ansätze zur Abschätzung des Hochwasserrisikos und zur Priorisierung von Hochwasserschutzmaßnahmen. In den Niederlanden finden monetäre Schadensabschätzungen Anwendung. Es haben sich zwei Hauptmodelle entwickelt. Eines wird auf Ebene großer Ereignisse wie Deichbrüche eingesetzt, das andere für regionale Fragestellungen und geringe Überflutungssituationen. Innerhalb ihrer Anwendungsgrenzen von kleinen bis großen Hochwasserereignissen liefern diese Modelle belastbare Ergebnisse.

Eine Weiterentwicklung bestehender Schadensmodelle könnte die derzeit heterogene Situation in Hinblick auf die Berechnung monetärer Hochwasserschäden und des Hochwasserrisikos vereinheitlichen. Dafür sind jedoch vergleichbare Daten zu Hochwasserschäden in den drei Ländern notwendig.

Samenvatting

Overstromingsgevaar- en overstromingsrisicobeoordelingen vormen een integraal onderdeel van de overstromingsrisicobeheercyclus en worden door de EU-richtlijn Overstromingsrisico‘s voor elke lidstaat vereist. De nationale vormgeving van de vereisten verschilt echter aanzienlijk binnen de EU en de Euregio Maasregio. Op basis van internationale literatuur en interviews met deskundigen werden de nationale administratieve voorschriften en technische regelingen voor de beoordeling van overstromingsrisico's uitgewerkt voor de Euregio Maasregio's in België, Duitsland en Nederland.

In alle drie de landen worden overstromingsrisico's op regionale schaal beschouwd, wat het voordeel heeft dat lokale expertkennis kan worden meegenomen. In België en Duitsland worden echter nog geen monetaire overstromingsschades berekend om het overstromingsrisico te bepalen. In plaats daarvan bestaan er verschillende semi-kwantitatieve benaderingen voor het inschatten van het overstromingsrisico en het prioriteren van maatregelen ter bescherming tegen overstromingen. In Nederland worden kwantitatieve modellen gebruikt voor het bepalen van monetaire schade. Er zijn twee belangrijke modellen: het ene model wordt gebruikt op het niveau van grote overstroming door bijvoorbeeld dijkdoorbraken, het andere op het niveau van regionale overstromingen met kleine inundatie dieptes. Binnen de grenzen van toepassing op kleine tot grote overstromingen leveren deze modellen interessante kwantitatieve resultaten op.

Een verdere ontwikkeling van bestaande schademodellen zou de huidige heterogene situatie met betrekking tot de berekening van monetaire overstromingsschade en overstromingsrisico's kunnen standaardiseren. Dit vereist echter vergelijkbare gegevens over overstromingsschade in de drie landen.

Résumé

L'évaluation de l'aléa inondation et du risque associé fait partie intégrante du cycle de gestion des risques d'inondation et est exigée de chaque état membre par la directive Inondations. Cependant, la mise en œuvre de celle-ci varie considérablement d'un pays à l'autre et même d'une région à l'autre, et ce tant au niveau européen qu'au niveau de la région Euregio Meuse. Sur base d'interviews d'experts, les pratiques d'évaluation du risque d'inondation ont été comparées entre les régions considérées de l'Euregio Meuse en Allemagne, en Belgique et aux Pays-Bas.

Dans les trois pays, le risque d'inondation est évalué au niveau régional, ce qui présente l'avantage de permettre d'intégrer des connaissances locales dans le processus. En Allemagne et en Belgique, les procédures officielles ne prévoient pas d'estimation monétaire quantitatives des dommages dus aux inondations pour déterminer le risque. A contrario, différentes approches semi-quantitatives sont privilégiées pour apprécier ce risque et pour prioriser des mesures de réduction du risque. Aux Pays-Bas, des modèles quantitatifs d'évaluation des dommages monétaires sont utilisés. Deux modèles principaux se dégagent, l'un étant utilisé pour des inondations majeures telles qu'induites par des brèches dans des digues, l'autre pour les inondations de plus faible ampleur. Dans les limites de leurs gammes d'application, ces modèles fournissent des résultats quantitatifs intéressants.

De futurs développements des modèles de dommages existants pourraient contribuer à uniformiser les approches actuellement hétérogènes entre les régions et les pays. Pour ce faire, il est toutefois nécessaire de disposer de données comparables dans les trois pays.

1 Introduction

1.1 Background

In July 2021, a storm front named 'Bernd' remained stationary over Europe for several days, resulting in persistent and heavy rainfall across a wide area (JUNGHÄNEL ET AL., 2021; CEDIM, 2021; MOHR ET AL., 2023). This excessive rainfall caused significant flooding along the Meuse and Rhine River basins in Belgium, Germany, Luxembourg and the Netherlands (ENW, 2021). The impact was particularly severe in the narrow valleys of the western German and Belgian low mountain ranges, as well as the adjacent transition zones to the lowlands (WVER, 2021). Water levels in the affected villages and cities along the flooded rivers reached 2 meters and even higher (JUNGHÄNEL ET AL., 2021).

Consequently, the region experienced severe damages, with a total of 200 recorded fatalities in Germany and Belgium (ENW, 2021), and hundreds of people injured (CEDIM, 2021). Numerous houses and villages suffered damage and partial destruction. The infrastructure was also heavily damaged, further complicating the situation for both the affected individuals and the aid workers. The event represents one of the most severe catastrophes in Europe in the past half century (MOHR ET AL., 2023).

In order to mitigate such extensive damages in future flood events, governments and water management professionals need to adapt and enhance all aspects of flood management. Since floods disregard national borders, the three countries of the Euregio Meuse-Rhine, connected by their rivers, must engage in transboundary and river basin-wide cooperation as a crucial step towards effective flood prevention and management (ENW, 2021).

1.2 Objectives

To enhance preparedness for future extreme flood events, the EMfloodResilience project was initiated. Lasting from May 2022 till December 2023, the project focuses on understanding the response of rivers and streams to heavy precipitation, identifying controlling parameters, and assessing the implications for specific geographical regions. This project aims to develop and improve products urgently needed by authorities and water managers in the Euregio Meuse Rhine, as was evident in 2021, to mitigate the future impacts.

To fulfil this objective, Work Package 5 focuses on the enhancement of flood damage models in the context of the 2021 heavy rainfall event and the damage model approaches currently used in the Euregio Meuse Region. As a first step, the present report (Deliverable 5.1.1) depicts the flood damage estimation approaches currently in place in the regions participating to the project. Subsequently, for Deliverable 5.1.2 and Deliverable 5.1.3, the damage that occurred during the 2021 flood event will be systematically recorded, analysed and compared with existing damage models.

1.3 Proceeding

To create the cross-border report, we performed literature research about flood damage modelling in a global context and about the procedure of performing flood damage modelling in the three countries of the Euregio Meuse Rhine - Belgium, Germany, and the Netherlands. In addition, interviews with experts of responsible authorities and other organisations were conducted in all three countries. Every interview is based on the same questionnaire (Appendix), which was set up in collaboration with the three universities of Liège, Delft and Aachen.

With the literature research and interviews it will be possible to compare the procedure of performing flood damage modelling between the three countries and identify advantages and disadvantages.

1.4 Content

This report has the following content:

- A list of identified public organisations performing flood damage analysis is provided in Table 1 (Section 2.2) on page 16.
- A description of the methods currently used for flood damage analysis in the three EMR countries is given in Section 3, starting on page 12.
- A discussion of advantages and disadvantages of the different methods can be found in Section 4, starting on page 26.
- Executive summaries of this report in German, Dutch, French and English are available at the beginning of this report.

2 Background and interviews

2.1 EU context

In 2006, the European Commission proposed the Directive 2007/60/EC (EU Floods Directive (FD)) (EU, 2007) with the aim to manage flooding events at an integrated scale and therefore reduce and manage the risks that floods pose to human health, environment, cultural heritage and economic activities. The FD entered into force on the 26th November of 2007 and had to be implemented into national legislation by each EU member state. The FD requests the EU member states to perform the following three steps:

1. Preliminary flood risk assessment
2. Flood hazard maps and flood risk maps
3. Flood risk management plans

Based on available or readily derivable information, the EU member states had to provide a first assessment of potential risk by 22nd December of 2011. Used information could be for example records and studies on long term developments, in particular impact of climate change on the occurrence of flood. The preliminary flood risk assessment has to be reviewed and if necessary, updated every six years. It must contain at least maps of the river basin districts and descriptions of the floods which occurred in the past. As a result, the EU member states have to identify those areas for which they conclude that potential significant flood risk exists or might be considered likely to occur (EU, 2007).

In Chapter III, the EU Floods Directive requests (EU, 2007) the preparation of flood hazard maps and flood risk maps for areas identified with significant flood risk. Flood hazard maps have to cover the geographical areas which could be flooded during a flood with a low probability (extreme event scenario), during a flood with a medium probability (likely return period ≥ 100 years) and - where appropriate - during a flood with a high probability. Thereby, the flood hazard map should include the flood extent, the water depths or water level and if possible, the flow velocity or relevant water flow variables. Meanwhile, the flood risk maps have to show the potential adverse consequences associated with the flood scenarios shown in the flood hazard maps demonstrated by the indicative number of inhabitants potentially affected, economic activity of the area potentially flooded, integrated pollution and prevention control installation, potentially affected protected areas identified by the Water Framework Directive (EU, 2000) and other information that is considered useful (EU, 2007). Figure 1 shows an example of a flood hazard map and a flood risk map in Germany, while Figure *2* and Figure 3 display examples of a flood hazard map and flood risk map in Belgium and Figure 4 and Figure 5 depict examples of flood hazard maps in the Netherlands.

Based on the created flood hazard and flood risk maps, the EU member states have to develop flood risk management plans, which should include measures for achieving flood risk reduction.

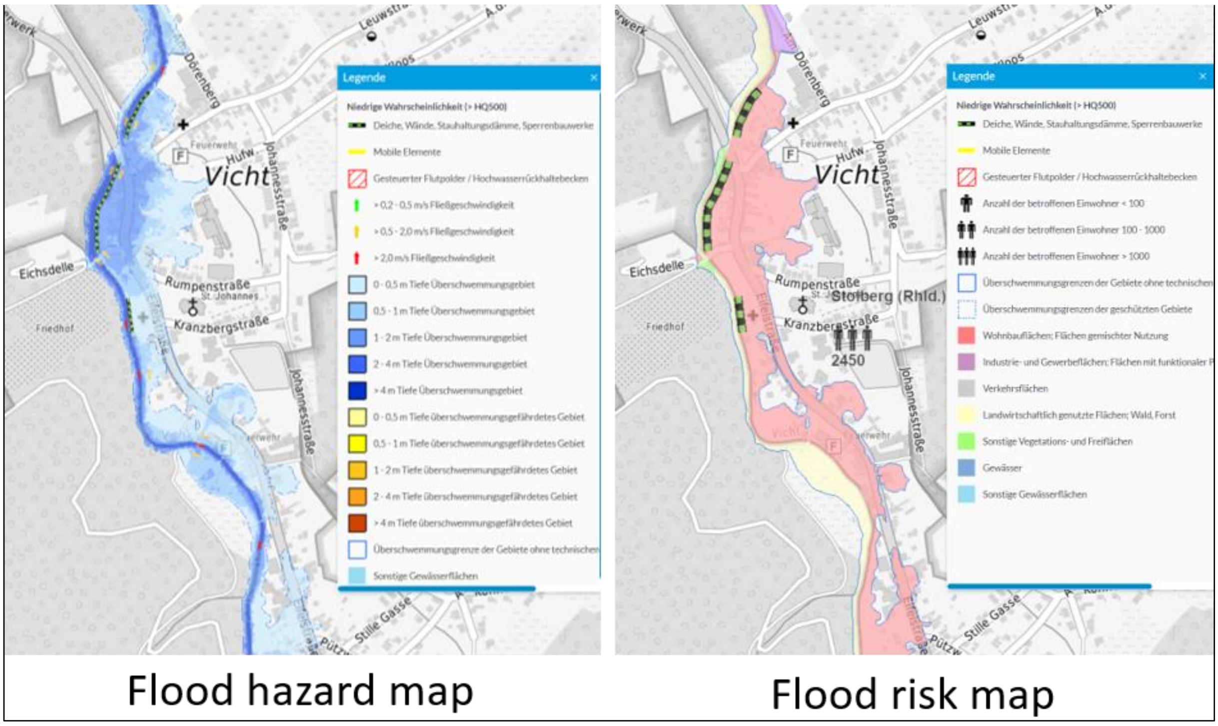

Figure 1: Example of a flood hazard map (left) and a flood risk map (right) in Germany, NRW

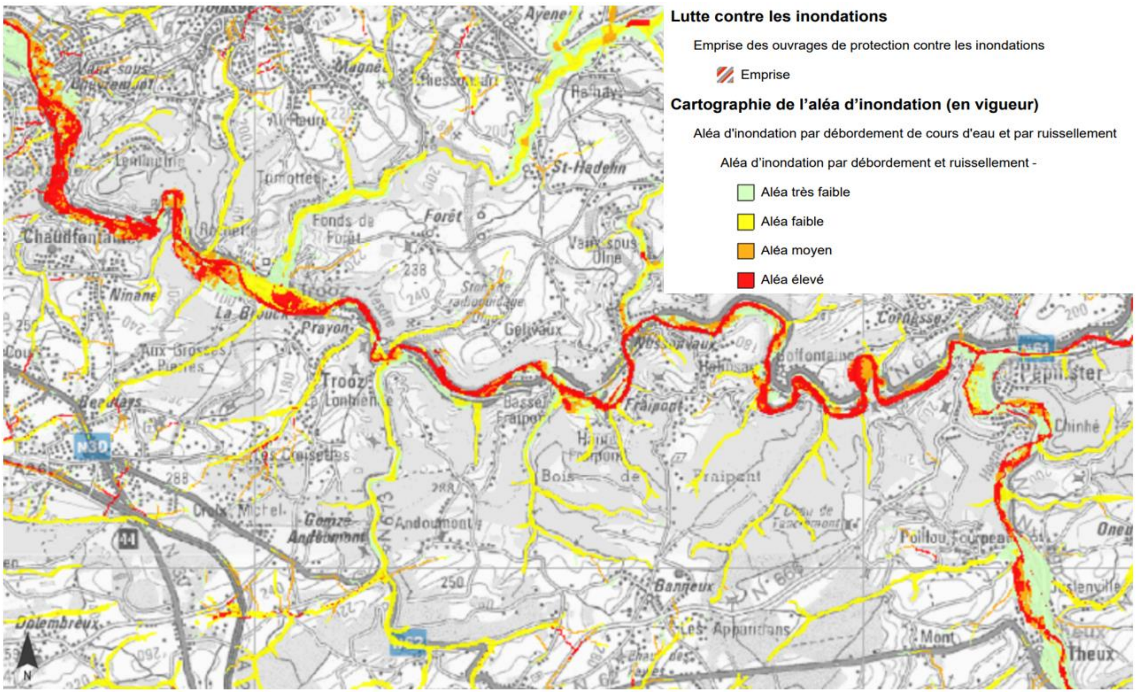

Figure 2: Example of a flood hazard map in Belgium, Walloon region.

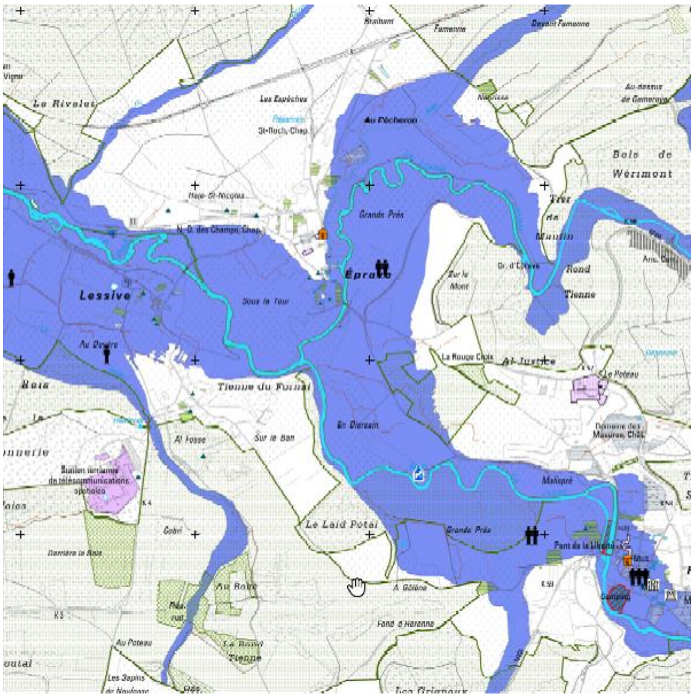

Figure 3 : Example of a flood risk map in Belgium, Walloon region.

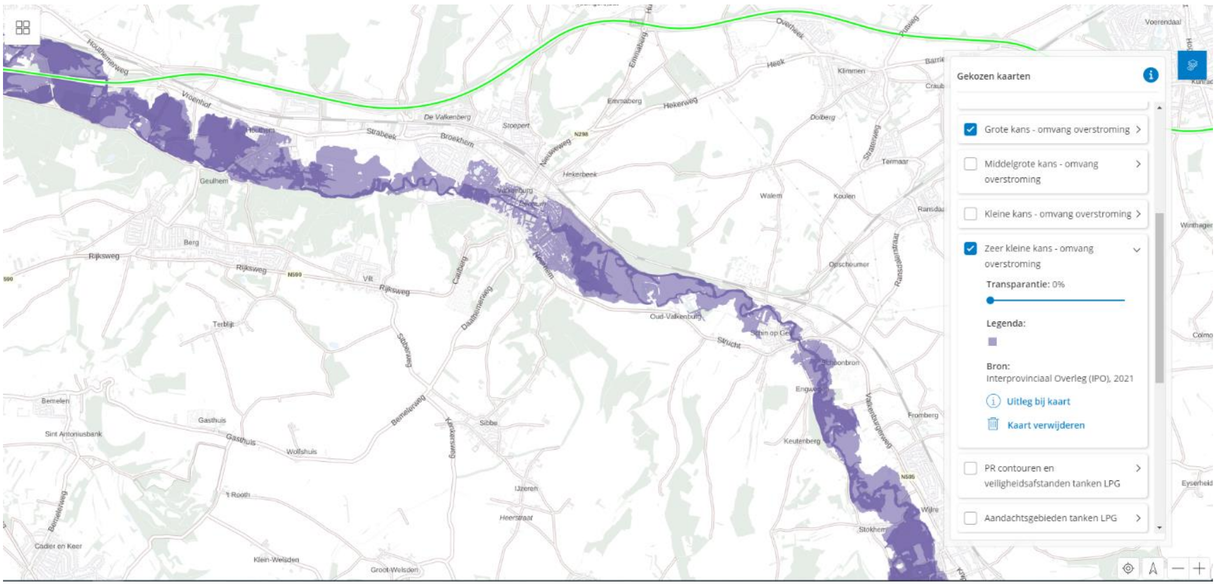

Figure 4: Example of flood hazard map on a national level in the Netherlands showing the extent of a flood event with a high probability (HQ10, dark violet) and a very small probability (HQ10,000, light violet) (Source: https://www.atlasleefomgeving.nl/)

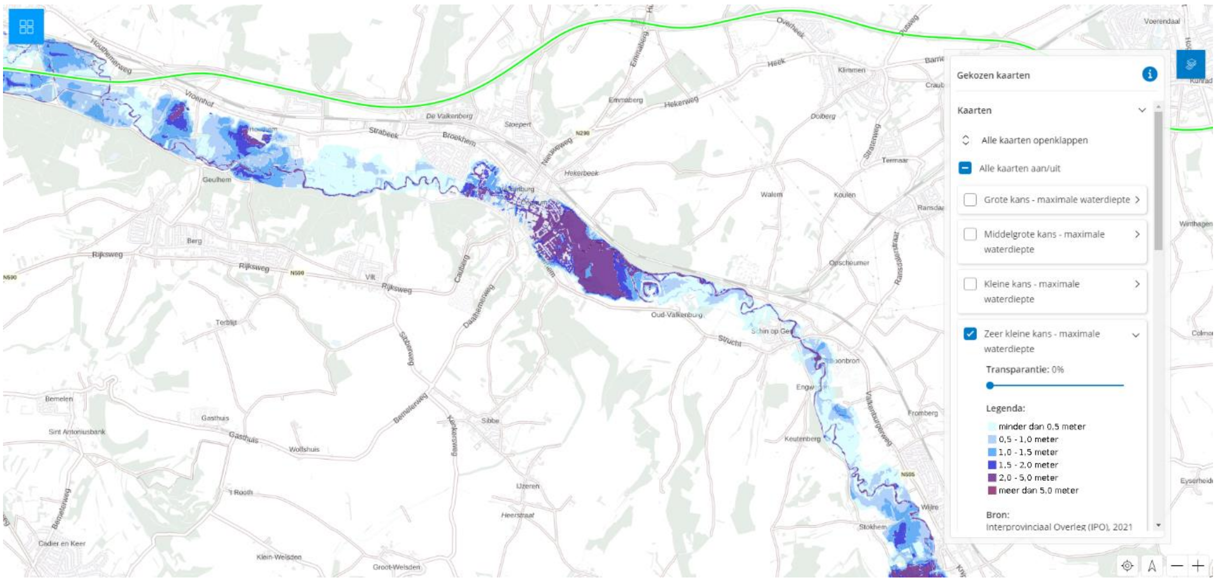

Figure 5: Example of flood hazard map on a national level in the Netherlands showing the maximum water depth for a flood event with a very small probability (HQ10,000) (source: https://www.atlasleefomgeving.nl/)

2.2 Interviews

Within the EU-funded project EMFloodResilience, a questionnaire about the use of flood damage modelling was developed and interviews were conducted with water authorities of the three EMR countries, namely Germany, the Netherlands and Belgium. In Germany, we focused on the water authorities in North Rhine-Westphalia (NRW). In addition, we conducted an interview with one consultancy office (Hydrotec, Aachen, Germany), that often calculates the hydraulics on behalf of the district governments in Germany. In the Netherlands, all regional water related authorities involved in the implementation of the EU Flood Directive were interviewed. In Belgium, we focused on provinces of the Walloon region and on the regional water authorities (SPW).

The aim of the interviews was to grasp additional information about the administrative usage of flood damage modelling in the EMR countries. As can be seen in Table 1, most public organizations we interviewed do not calculate monetary estimates of flood-induced damage. Conversely, semi-quantitative approaches (e.g., score-based) are generally adopted, with a focus set on identifying the exposed assets (e.g., counting the number of affected buildings).

Table 1: List of identified public organizations performing flood damage modelling. (B = Belgium, D = Germany, NL = Netherlands)

Country	Authority / Organisation	Flood hazard modelling	Flood risk modelling – semi-quantitative approach	Flood risk modelling – standardised monetary estimation
B	Province of BW (Brabant Wallon)	Externally	Yes	No
B	Province of Hainaut	Internally and externally	No	No
B	Province of Liège	Externally	Yes	No
B	Province of Namur	Externally	Yes	No
B	Service public de Wallonie (SPW)	Externally	Yes	No
D	Bezirksregierung Düsseldorf	Yes	Yes	No
D	Bezirksregierung Köln	Yes	Yes	No
D	Bezirksregierung Münster	Yes	Yes	No
D	Hydrotec (Consultancy Office)	Yes	Yes	Yes
D	State Ministry NRW	No	No	No
NL	RWS-WVL (Rijkswaterstaat Water, Traffic and Environment Service)	Yes	Yes	Yes
NL	Water Authority Limburg	Yes	Yes	Yes
NL	Province of Limburg	No	No	No
NL	Deltares (Consultancy Office)	Yes	Yes	Yes

3 Methods used for flood damage analysis

3.1 Germany (NRW)

Germany is a country with a federal structure, meaning that all the federal states are led by their own ministries including the ministry of the Environment. The different federal states, in turn, confer more legislative authorities to the regions (Bezirksregierung (BZ) = district governments). The federal state North Rhine-Westphalia, which was highly affected by the flood of July 2021 is divided into five district governments as shown in Figure 6.

Figure 6 : District governments (Bezirksregierungen) in North-Rhine-Westphalia (source: https://www.nordrhein-westfalen-gastgeber.com/regionen.html)

The district governments are the authorities in charge of the realization of the steps demanded in the EU Floods Directive (see Section 2.1): conduct preliminary flood risk assessment, set up flood hazard maps and flood risk maps and develop flood risk management plans. They report their results to the federal ministry in Düsseldorf, who has to report the result to the EU. Another task related to floods is the designation of flood plains and the information of the population. One of the tasks of the federal state ministry in Düsseldorf is to coordinate the five district governments in NRW. Superior to the federal state ministries but without authority to make legal decisions is the LAWA, the German working group on water issues of the federal states and the national government. The LAWA coordinates transfederal working groups and develops recommendations.

The EU Flood Directive does not stipulate to perform any flood damage modelling, neither does any other legal provision in Germany. This is why the district governments of NRW generally do not perform any damage modelling but follow the working cycle of the EU Flood Directive.

Flood hazard and exposure modelling are expressed by creating the flood hazard maps. Hydraulic calculations are mostly done by consultancy offices in 2D, with the software Hydro AS-2D by Hydrotec or with software compatible with HydroAS. Sometimes, the software Mike 21 (BZ DÜSSELDORF, 17.05.2023) and Sobek are, or rather were, also used. Some 1D calculations are done with the software Jabron.

The EU Flood Directive nominates three different scenarios, that have to be considered in flood hazard maps: floods with a high, medium and low probability. The district governments calculate with events between 5 – 20-years return periods for floods with a high probability, with a 100-year return period for floods with medium probability and with a return period of 200 – 1000-years for floods with a low probability. At the moment, it is discussed if a fourth and a fifth scenario are needed to be calculated, which would refer to a flood with an extremely low probability (return period 10.000 years) and to a flood with a probability between medium and low probability (HYDROTEC, 26.05.2023).

The estimation of flood exposure and hazard are respectively carried out by the highlighted flooded area. This area is associated with water depths and flow velocities. Flood damage and risk modelling are expressed by creating the flood risk maps, where the potential flood damage and risk is estimated by highlighting critical infrastructures and giving an estimated number of affected people. Currently in NRW, no damage modelling approaches including standardised monetary flood damage models are used in the general large-scale process of flood risk determination. Some calculations are made for small-scale situations, where very expensive flood protection measures are planned and therefore a detailed estimation of costs and benefits is desired (BZ KÖLN, 28.06.23). No details about the process is given here because every situation was treated individually.

In 2022, the third cycle of the EU Floods Directive started and the updates of the preliminary flood risk assessments by the district governments are ongoing. This has to be done by the end of 2024, including reporting the results to the EU. During the first two cycles, the preliminary flood risk assessment, including identifying the areas at risk, was done without any standardised calculation of potential monetary damage. The assessment has mainly focused on protected areas and other vulnerable areas. Some monetary assumptions were made on the basis of residential units (BZ DÜSSELDORF, 17.05.2023). Considering a 100-year-flood, a water body was called a water body at risk as soon as an estimated damage of 500,000 Euro was reached. This would mean ten residential units to be affected, assuming 50,000 Euro damage per residential unit (MUNV NRW, 07.06.2023). This semi-quantitative approach to flood damage estimation relies on expert knowledge and does not include the relationship between water depth or flow velocity and damage extent to the building. However, if used uniformly across areas, it is suitable to compare flood risks to a certain amount. No other approaches regarding standardised monetary or semi-monetary estimation of flood damage were reported by the authorities in Germany.

In January 2018, the working group "Flood protection and hydrology" of the LAWA decided to standardise the estimation of monetary flood damage as a criterion to identify the water bodies at risk Germany-wide uniformly. The water bodies at risk identification has to be done in the first step of the cycle of the EU Flood Directive. The idea is to use the BEAM (Basic European Assets Maps) dataset 2021, which is a standardised set of area-related assets in Germany. Based on polygons it contains spatial data on land use and land cover as well as assets extracted and derived from official statistics and supplementary sources and summed up in asset categories (LAWA, 2022). Land use and land cover data within the BEAM dataset are based on the Corine Land Cover which is collected by the EU according to uniform criteria and mapping standards (LAWA, 2022). Only direct tangible assets are considered.

Monetary damage is calculated on a large scale in Euro per river km and commune. Furthermore, a threshold to identify the water bodies at risk has to be defined. The working group is aiming to develop a standardised procedure for damage potential determination and is still working to define a threshold (BZ DÜSSELDORF, 17.05.2023). Currently, the procedure is still in a test phase and is being applied in the current evaluation cycle of the EU Floods Directive.

This idea to standardise the identification of water bodies at risk is no legal decision but a LAWA-recommendation, which the federal states do not have to follow but as they are part of the LAWA working groups they are mostly motivated to put those recommendations into practice.

3.2 Belgium

Belgium is a country divided in three regions: the Walloon region, the Flemish region and the region of Brussels. The focus was set here on the Walloon region, which was particularly affected by the July 2021 flood. It is composed of five provinces: the Province of Liège, the Province of Hainaut, the Province of Brabant Wallon, the Province of Namur and the Province of Luxembourg (Figure 7). The SPW (Public Service of Wallonia) is the organization in charge of water management the regional level.

In the Walloon region, water management is handled at different administrative levels depending on the type of river or stream, as summarized in Table 2. Waterways, such as the Meuse and the Albert canal, are managed by the Mobility and Infrastructures department of SPW (SPW-MI), i.e., at the regional level. On the other hand, non-navigable rivers are classified into categories. The main non-navigable rivers (Category 1), such as river Vesdre and the lower part of river Hoëgne, are managed by another department of SPW (SPW-ARNE), hence also at the regional level.

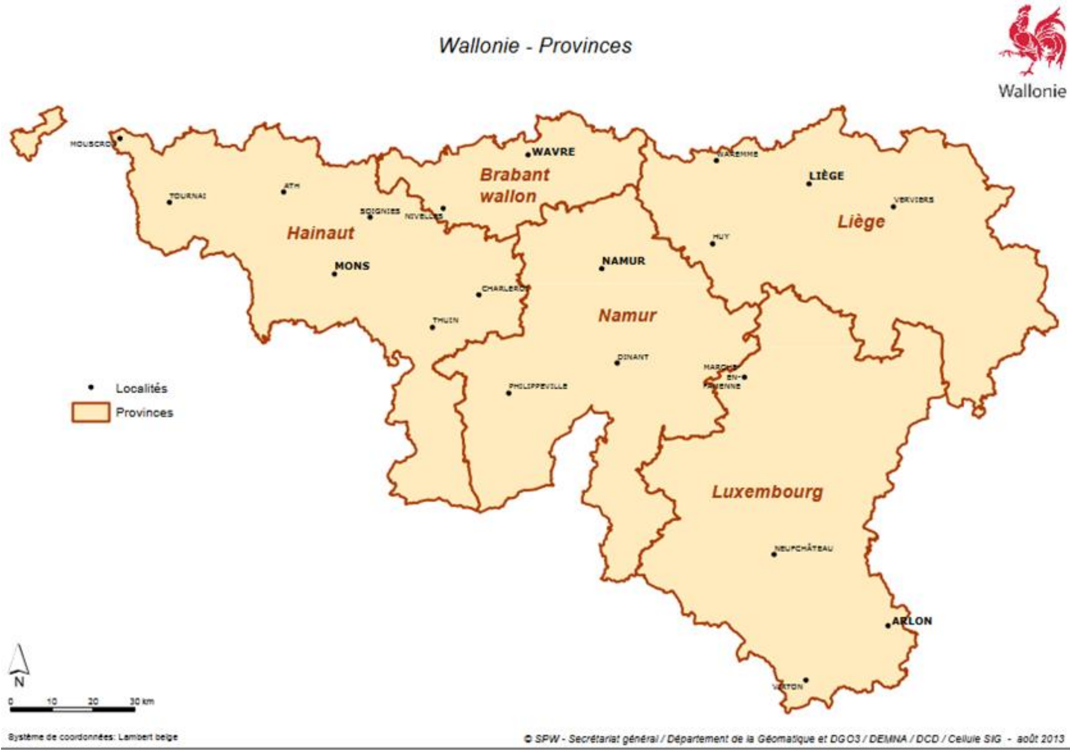

Figure 7: Provinces of the Walloon Region (Source: https://www.wallonie.be/fr/acteurs-et-institutions/provinces)

Table 2: Level of responsibility for the management of rivers and streams in Belgium (Walloon region)

Waterways	**Non-navigable rivers**			**Unclassified streams**
	Category 1	Category 2	Category 3	
SPW MI (regional level)	SPW ARNE (regional level)	Respective provinces	Respective municipalities	Landowner

Smaller rivers (Category 2) are managed at the province level and even smaller streams (Category 3) are managed by municipalities. For instance, the Province of Hainaut is in charge of 1,600+ km of

Category 2 rivers and also provides some support for studies related to Category 3 rivers. Major floods occurred in the Province of Hainaut in 2002, 2005, 2010, and 2016, among others. The Province of Liège manages rivers such as the Geule (flowing to Valkenburg), the Wayai (Spa) or the Magne (right bank tributary of river Vesdre). The Province of Namur is responsible for 1,350 km of Category 2 rivers. In the framework of a partnership with 38 municipalities in the province of Namur, the Province also maintains 800 km of streams of Category 3 (formally under the responsibility of the municipalities).

In the Province of Hainaut, besides a group in charge of maintenance of Category 2 rivers, another group (called NAQiA, referring to a Babylonian goddess) is specifically focused on reducing flood risk in the province. This is different from other provinces in Belgium. Major achievements of the NAQiA group include systematic topographic surveys of all Category 2 rivers in the Province of Hainaut, but also all Category 3 streams and unclassified streams when they contribute to flood risk in the Category 2 rivers located downstream. NAQiA has developed a partnership with an organization specialized in topographic surveys of artificially covered streams, based either on conventional surveys (manual) or using unmanned technologies.

Hazard modelling and scenarios

For all provinces and the SPW, the hydraulic computations performed to generate fluvial flood hazard maps are based on a blend of one- and two-dimensional computations. So far, there is not a single standard software used for this modelling across the whole Walloon region. Fluvial flood hazard maps for major rivers are generally based on hydraulic computations performed either by universities or by consultancy offices. The design and creation of the final flood hazard (and risk) maps is conducted by SPW.

The most standard scenarios considered for fluvial flood risk management by SPW and the provinces correspond to design floods with return periods of 25, 50, and 100 years. An additional “extreme” scenario, in which the 100-year event is magnified by 30%, is also considered in several river stretches. An upgrade of this approach is foreseen, in which the extreme scenario would be defined by an estimate of the 1000-year flood.

For the smaller rivers managed at the provincial level, calculations are mostly based on design storms. Chicago-type storms are generally assumed for the Provinces of Brabant Wallon, Liège and Namur. They enable representing intense summer rain events which typically induce flood damage in these territories. As much as possible, the outcomes of the hydrological model forced by synthetic Chicago-type storms is compared against field data from past flood events.

Besides the return periods considered for fluvial flood risk management by SPW, storms of lower return periods are also analysed. A 10-year return period is typically considered by the Province of Liège and the Province of Brabant Wallon. Flood risk studies in the Province of Hainaut also cover the whole range of return periods from 1 to 25 years. A 25-year return period is usually considered as the target for protection. A return period of 50 years is also targeted when the extra cost remains reasonable in light of local constraints. The 100-year return period scenario is also considered in the modelling, but it is not a target for protection. Province of Brabant Wallon also tests the 100-year event magnified by 30%.

Contrary to other provinces, the Province of Hainaut conducts part of the hydrodynamic modelling studies internally. The civil engineering design and sizing of flood reduction measures (e.g., flood storage zones, increase stream conveyance, derivations …) are performed internally by the province as well as the follow-up of the construction and the maintenance (e.g., valves, desilting …). The latter is growing in importance as the number of constructed measures has grown over the last years.

Analysis of exposure and damage estimation

The vector database Projet Informatique de Cartographie Continue (PICC, link) is used to identify the assets-at-risk (e.g., buildings, plots of land …) in most cases (Provinces of Liège, Brabant Wallon …). For the Province of Hainaut, visual inspection of modelling outcomes has been used since the streams are small and the number of assets-at-risk remains limited. SPW uses mostly the landuse map, WalOUS, to identify the assets-at-risk (e.g., buildings, plots of land …). Other datasets owned by SPW are also used, as well as external data (e.g., from the federal office of statistics Statbel).

Unlike in the Netherlands, the Walloon Region of Belgium has neither a national nor a regional standard enforcing a particular method for flood damage modelling. Therefore, the methods employed vary based on location and on the consultancy in charge of the study.

On a regular basis, the provinces commission consultancy offices to study flood risk reduction measures (e.g., design and sizing of temporary storage, flood defences …). In the case of the Province of Liège, some studies include an evaluation of the avoided risk resulting from various possible measures. This assessment is based on estimates of flood damage; but since there is no standardized approach, the contractor is free to choose a particular damage estimation method. Due to the absence of a generally accepted flood loss model for Wallonia, score-based methods are used by the Province of Liège. An example of such a model takes the form of a table, in which a score is given as a function of the range of inundation depth and the type of asset-at-risk (say, building vs. plot of land). This only provides a semi-quantitative view of the flood impact. Sometimes, only the number of affected buildings is counted. In this context, the risk is estimated as the sum of the scores obtained for each considered scenario, multiplied by the corresponding frequency. However, the obtained number is used solely for prioritizing projects, and it does not reflect an absolute gain in terms of avoided risk. Similarly, in the case of the Province of Namur, flood damage assessment is conducted by consultancy offices using various methods.

Conversely, in the case of the provinces of Brabant Wallon and Hainaut, the studies do not include a quantification of (avoided) flood damage nor a formal estimation of (the change in) flood risk. The main reason for this is that, given the relatively limited size of the streams under consideration, the studies tend to cover a reduced spatial extent (e.g., one village) and the (changes in) impacts are very localized, so that a visual inspection of hydrodynamic modelling outcomes makes it obvious as to which is the change in exposure. Besides, implementing a strict cost-benefit analysis is not in line with the strategy of provinces, such as the Province of Hainaut, which may consider that reducing flood hazard is part of the services a province is committed to offer to citizens, rather than to force citizens to move for reducing flood risk. Nonetheless, there are general guidelines, such as: the province does not invest for protecting just gardens or basements.

An academic flood damage model was recently adapted to the Belgian context (SCORZINI ET AL., 2022) and was applied by the Province of Namur to estimate the avoided damage of particular hazard reduction measures in a pilot case (village of Crupet).

EU Flood directive and prioritization of measures

Among other responsibilities linked to water management in the Walloon region of Belgium, SPW is in charge of the preparation of preliminary flood risk assessment (PFRA), flood hazard and flood risk maps (FHRM), as well as flood risk management plans (FRMP), as prescribed by the Floods Directive (Section 2.1).

SPW produces (hazard and) risk maps according to the prescriptions of the Floods Directive (2007/60/EC). These maps do not contain actual estimates of flood damage, but they overlay flood hazard information with a representation of the main assets-at-risk, as shown in Figure 3. Symbols indicate the range of the number of potentially affected people and buildings. A colour code is used to display the type of activities prevalent in the floodplains (public services, education, health services, business, recreational use, agriculture). Other symbols highlight critical infrastructures at risk in various sectors (e.g., communication, water supply, energy, wastewater treatment), potential sources of pollution (e.g., industries dealing with hazardous material), cultural heritage, transport network, natural assets … Visual inspection of these risk maps provides a qualitative appraisal of vulnerability and risk.

For the preparation of the flood risk management plans, SPW has developed a methodology for prioritizing flood risk reduction measures based on multi-criteria analysis (MCA). Although there is no regional standard in Wallonia for flood damage modelling, a single, harmonized procedure is used for prioritizing measures in the preparation of flood risk management plans, which ensures consistency throughout the region. Considered flood risk reduction measures are evaluated along four dimensions: (i) flood risk, (ii) biodiversity, (iii) economy, and (iv) socio-cultural aspects. The effect of a particular measure on flood risk is appreciated through several indicators in a semi-quantitative approach (Service Public de Wallonie, 2021). The multi-criteria analysis underpinning the prioritization of flood risk reduction measures is performed directly by SPW.

A new methodology, that is currently being developed by an Expert Panel on Resilience relies on a vulnerability score, including the following levels: Critical vulnerability, High vulnerability, Medium vulnerability, Low vulnerability, No vulnerability, and Not applicable (Service Public de Wallonie, 2022). This new methodology aims at comparing the situation before and after implementation of a measure. This is not the case in the current approach used in the framework of the FRMP, which only aims at prioritizing projects, and not precisely at comparing the projected to the baseline situations.

Perspectives

The interviewed stakeholders stressed that the relatively simple (semi-quantitative) approaches used are overall consistent with the level of data availability for calibrating damage models, which was limited particularly before the 2021 floods. Though the interviewees did not report on specific plans to upgrade the current approaches for flood damage estimation, they expressed interest for improvements, such as those emerging from the present EMfloodResilience project. One particular incentive for improving flood damage estimation procedures is a growing interest by decision-makers for cost-benefit analysis of the planned measures.

3.3 The Netherlands

The Dutch are well-known when it comes to water safety. The low lying country of the Netherlands has been building flood protection structures since history to protect itself from floods. Approximately 50% to 60% of the country is flood prone. This shows the need to be flood resilient and is the reason why flood safety standards are included in the law via the Dutch 'Water Act'. To obtain safety standards that are feasible and cost-effective, it is important to have a good estimate of the possible damages related to certain floods and their return periods. Various methods are used within the Netherlands to translate flood risk maps to damage estimates. This section introduces the commonly used methods in the Netherlands in relation to the area of Limburg.

In the Netherlands, there are different layers of water authorities in charge of setting flood safety standards for primary dikes but also for regional dikes and regional areas. The ministry of I&W (ministry of infrastructure and water management) decides on the flood risk standards of the primary water system, national waterways and flood surge barriers. Rijkswaterstaat advises in this matter. The 12 provinces in the Netherlands are in charge of translating the Dutch water act law into flood safety standards for regional areas (PROVINCE OF LIMBURG, 2023). The flood safety standards of the primary flood defences are based on loss-of-life and cost benefit analysis.

The 21 Water Boards of the Netherlands are in charge of meeting the safety standards of most of the dikes in the Netherlands with a few exceptions like the Julianakanaal. Rijkswaterstaat is in charge of meeting the flood safety standards of the additional water defences (voorliggende keringen), structures on national waterways, flood surge barriers and dikes of some national water ways like the Julianakanaal.

For large rivers and primary dikes, the "Schade en Slachtoffer module" (SSM2017) is commonly used by Rijkswaterstaat as a damage and loss-of-life modelling method (RIJKSWATERSTAAT, 2023). A different damage model, the WaterSchadeSchatter (WSS), is more commonly used by Water Boards in regional areas. Some Water Boards also decide on using mainly rule-of-thumb calculations for damage modelling, to quickly assess risks and measure flood impact.

The key-difference between SSM2017 and the WaterSchadeSchatter (WSS) are (SLAGER, 2023):

- Damage functions of both models:
  - SSM2017 uses 57 damage/loss of life functions, which are subcategories of the following 5 categories:
    - Commercial
    - Housing
    - Infrastructure
    - Loss of life
    - Other
  - WSS uses 33 damage functions, which are subcategories of the following 4 categories:
    - Buildings
    - Infrastructure
    - Agriculture
    - Nature and recreation

- Applicability regarding water depths:
    - Between 1 cm and 30 cm for the WSS, with a maximum damage factor is reached at 15 cm inundation depth for buildings
    - Between 1 cm and 5 m for the SSM2017, although commonly used for high water depths
- Maximum resolution that can be used:
    - 0.5 m x 0.5 m with the WSS
    - 5 m x 5 m with the SSM2017
- SSM2017 also includes loss-of-life analysis
- Input for the models are:
    - WSS: water levels (meter NAP) series
    - SSM2017: uses output of flood models; max water depth, max flow velocity, max rise of depth.

For regional areas, the assessment of the flood safety standards is done with a water system analysis performed by the Water Boards. Within these assessments, bottlenecks are located. The next step is to analyze if and how the bottlenecks that cause failure of meeting the flood safety standards can be resolved by measures. This is done in combination with cost-benefit analyses where flood damage modelling is an important factor. The Water Board uses a rule of thumb calculation with a fixed cost per floor area to calculate the benefit of measures for regional studies caused by rainfall in the catchment (WATERSCHAP LIMBURG, 2023). For regional waters, HQ10, HQ25 and HQ100 return periods are included in the modelling approach. In the future, HQ500 and HQ1000 scenarios are likely to be modelled too. By adding scenarios, the more extreme events are also included in the approach. Most urban areas in the south of Limburg, like Valkenburg, have a safety standard corresponding to a HQ25 return period. There is an ongoing effort by the Water Board of Limburg to obtain higher protection levels for the urban areas in the south of Limburg.

4 Discussion

Based mostly on expert interviews in Germany, Belgium and the Netherlands, the administrative responsibilities and technical details of flood risk assessment have been studied in this work package. The comparison of these aspects shows some similarities and several differences between the three countries (Table 3). Based on these, advantages and disadvantages of the approaches used in the three countries can be identified.

We collected information on flood damage estimation procedures in three countries (Germany, Belgium, and the Netherlands), with a focus on the following regions: North Rhine-Westphalia (Germany), the Walloon Region (Belgium), and the south of Limburg (the Netherlands). In none of these regions, a single standardized procedure is in place for flood damage estimation. In the areas of interest in Belgium and Germany, the approaches used are highly case-dependent. In some cases, such as for relatively small streams, the approach is as simple as a visual inspection of the inundation extent to assess the exposure, without any quantification of damage. When higher investments in risk reduction measures are at stake, semi-quantitative approaches are generally used (e.g., based on land use category and count of number of affected people, or score-based approaches, i.e., without monetary quantification), but the exact method depends on the authority in charge and in some cases even on the consultancy hired for conducting the study. In the Netherlands, the situation is different, since some mainstream damage modelling methods can be identified: SSM for the main river systems, and WSS at the level of regional waterboards. These methods provide quantitative estimates of flood damage in the following sectors: Commercial, Housing, Infrastructure, Loss of life, Other (SSM) and Buildings, Infrastructure, Agriculture, Nature and recreation (WSS). They are systematically used to design, size and select flood risk reduction measures in the Netherlands. However, the aforementioned models have limitations regarding the intensity of a flood event they work well for.

The lack of a standardized approach across sub-regions / provinces, and to a greater extent between countries, impedes comparison of flood hazard and flood risk over different regions. However, within one (sub-)region the comparability may still be good (e.g., consistent approach used throughout the Walloon region to prioritize risk reduction measures). On the other hand, the pragmatic, semi-quantitative approaches appear effective in practice and offer the advantage of remaining reasonably data demanding.

Though the considered regions in Belgium and in Germany do not perform monetary damage estimations so far, there are plans or pilot studies in both regions aiming at a more quantitative approach of flood damage calculation. In Germany, the BEAM data set is planned to be used in the future to easily calculate a monetary flood damage. In Belgium, the academic damage model INSYDE-BE has been proposed and has been tested by stakeholders. In the Netherlands, no plans for changes are known, except for a continuous effort to improve the damage functions.

The numerical models used for flood hazard calculations are usually a blend of 1D and 2D models irrespective of the considered region. Hence, the base for flood hazard maps and flood risk maps are similar between the three regions.

Table 3: Comparison of flood risk assessment approaches in Germany, Belgium and the Netherlands in the regions considered in the interviews and research of this project

	Germany (NRW)	**Belgium (Walloon Region)**	**The Netherlands**
State-wide uniform approach	No	No	Yes (SSM2017, WSS)
Main level of responsibility	Regional / district (Bezirksregierungen)	Region and provinces, depending on the river	Mostly regional (Water boards); RWS in some cases
Numerical model used for flood hazard modelling	Blend of 1D and 2D, mostly 2D	Blend of 1D and 2D, mostly 2D	Blend of 1D and 2D
Return periods considered for "high probability" flood scenarios	HQ5 – HQ20	Regional level: HQ25, HQ50 Provincial level: between 1-year and 25-year storms for design, 50-year if reasonable cost	Regional level: HQ10-HQ25 National level: HQ 10
Return periods considered for "medium probability" flood scenario(s)	HQ100 (for design)	Regional level: HQ100 Provincial level: 100-year storm (for testing, not for design)	Regional level: HQ100 National level: HQ100
Return periods considered for "low probability" flood scenario(s)	HQ200 – HQ1000 (for extreme events)	Regional level: HQ100*1.3 (in some rivers only, update planned) Provincial level: 100-year storm × 1.3 (for testing only)	National level: HQ1000-HQ10,000
Return periods under consideration for future upgrades of the procedures	HQ10,000	Regional level: HQ1000	Regional level: HQ500, HQ1000
Flood damage models	Number of affected people Category of land use	Mostly score-based semi-quantitative approaches, or none	SSM by Rijkswaterstraat WSS on regional level
Plans for future / further development	Implementation of BEAM data set Guidelines to standardise flood damage calculation	Work group on resilience for new criteria to prioritise flood risk reduction measures	Not at the moment

Overall, all the approaches in Germany, Belgium and the Netherlands have their value and have been successfully applied over the last years. The flood hazard maps and flood risk maps that result from these flood risk assessments have been used to create flood risk management plans and hence have been an integral part of flood risk mitigation. A particular advantage lies in the consideration of flood areas and flood risks at regional level. By involving local administrations, valuable local knowledge and expertise flow into the risk assessments, which could not be considered on larger scales.

On the other hand, there are different flood risk model components in every country within the Euregio Meuse Region, which hampers the comparability of results in a cross-border point of view. An obvious example is the difference of return periods that are considered in the three countries. The return periods for design events as well as "extreme" events differ, making it almost impossible to do a simple comparison of flood risk security and residual risks in the Euregio Meuse Region. Different flood damage models strengthen these discrepancies further.

5 Conclusion and prospects

Work package 5 aims at enhancing flood damage modelling approaches currently used in the Euregio Meuse Region, considering new data and knowledge available in the aftermath of the 2021 extreme flood event. Therefore, as a first step, the flood damage estimation approaches used in the regions participating in WP5 of the EMFloodResilience project were analysed. This first step is important to gain an overview of the current situation and identify the starting point of further developments.

The basis for all flood risk assessments in Germany, Belgium and the Netherlands is the EU Floods Directive. However, the national incorporation of this directive varies between the countries. Two obvious differences in flood risk considerations concern the return period of the flood events considered and the details of flood damage modelling. The former is problematic if cross-border comparisons or reconciliations are to be made on the basis of the existing flood hazard maps and flood risk maps. The same applies to the second point. If the differences in the methods and approaches used are not sufficiently communicated, discrepancies can arise in cross-border considerations, especially with regard to flood damage modelling.

All approaches in the three countries have their own value and raison d'être, as they can be usefully applied to the respective regions. However, there is currently a lack of uniform approaches in both Germany and Belgium to assess the monetary damage and thus the risk of flooding, though further developments have been initiated in both countries. However, robust data sets regarding the damage functions for flood events that can be used for the areas at hand are still scarce.

It is part of work package 5 to further work on the issue of flood damage modelling in the Euregio Meuse Region regarding comparability of approaches as well as consideration of “extreme” events such as the 2021 flood. Therefore, it is the objective of deliverable 5.1.2 and 5.1.3 to (a) take a closer look at the flood damage that occurred in 2021 and (b) the possible further development of flood damage models that fit the Euregio Meuse Region.

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Appendix: Interview questions

Interview on flood damage modelling

1. Introduction
   1.1. Please tell us a bit about yourself and your organization
2. Flood damage modelling in your organization
   2.1. What legal or regulatory requirements exist in your country with regard to flood damage modelling?
   2.2. What is your organization's role in the process of flood damage modelling?
   2.3. Are there institutions that work with you in the process of flood damage modelling? Are the different steps of flood damage modelling all located within your organization?
3. Flood hazard and exposure modelling
   3.1. If used, what kind of hydrodynamic (CFD) model is used in your organization to calculate flood events (Software; 1D, 2D, 3D)?
   3.2. What flood scenarios are taken into consideration in your organization?
   3.3. How is exposure to flood estimated in your organization?
4. Flood damage and risk modelling
   4.1. How do you estimate the damage / costs during a flood event in your organization?
   4.2. If applicable: What flood damage models do you use in your organization? Do you have different types of models for pluvial and fluvial flood events?
   4.3. To the best of your knowledge: Is the process of flood damage modelling the same for all areas in your country? Are there regional differences?
   4.4. What are – in your opinion – the advantages and disadvantages of the flood damage model / damage estimation approach you use?
   4.5. Are there plans to change the flood damage model you use?
   4.6. How is flood risk estimated in your organization?
5. Miscellaneous
   5.1. Do you have anything else you would like to tell us about flood damage modelling in your organization?